# Testing The Effects Of Price Responsive Demand On Uniform Price And Soft-Cap Electricity Auctions

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## Abstract

Testing auction mechanisms experimentally in a controlled environment provides an inexpensive means for evaluating their relative merits. This paper describes a framework for testing the efficacy of a price-responsive load on a uniform price last accepted offer and a soft-cap market. Experimental evidence to date based on uniform price market testing has shown an ability of price responsive load to mitigate high volatility and average price. The paper addresses a process to validate these results as well as our hypothesis that price responsive load will mitigate high soft cap market price behavior such as that observed in California.

## Introduction

The California market for electricity meltdown that occurred this past year occurred in part because residential customers were exposed to severe economic risk and financial hardship in places such as San Diego. As a result, the FERC proposed major modifications to the structure of the wholesale market for power (FERC Order, 11/1/00). One of the proposals was to place a "soft-cap" on market prices at $150/MWh. This represented a radical modification to the structure of the auction used to determine spot prices for electricity in the wholesale market. The new auction proposed by the FERC was implemented in January, 2001.

In a soft-cap auction, offers to sell below the cap of $150/MWh are used to determine a single market clearing price for all accepted offers in a standard uniform price auction. If the total capacity offered below $150/MWh is insufficient and some offers greater than $150/MWh are needed to meet the load, suppliers are paid their actual offers in a discriminative auction for all offers above $150/MWh. Hence, a soft-cap auction is a hybrid between a conventional uniform price auction and a discriminative auction.

The soft-cap market has not worked well. Spot prices for electricity in California remained consistently around $300/MWh from January to April, 2001, or roughly ten times higher than the previous year. Since the soft-cap market did not bring spot prices down to competitive levels, a new FERC Order (April 26, 2001) proposed to "replace the $150/MWh breakpoint plan adopted in its December 15, 2000 order" (FERC Docket No. EL00-95-012, p. 1). The proposed modifications to the market combine a highly regulated uniform price auction, based on "true" costs, with a discriminative auction for higher offers. Additional modifications to expand the regional and temporal coverage of this new market structure were adopted in FERC Order (EL00-95-031)

This paper sets the framework for reporting on a series of laboratory experiments to assess the performance of different electric power markets with respect to price volatility and average market price. In particular, the experiments compare conventional uniform price auctions, with and without price responsive load, with a soft-cap auction like the FERC/California with and without price responsive load. Since the computational complexity of determining equilibrium strategies in a multi-player, multi-unit game is too intractable to derive useful analytical results (Klemperer and Meyer, 1989), testing market performance using experimental economics is a practical way to proceed. Green and McDaniel (1999) have explored some of the implications for electricity markets in a theoretical analysis for a competitive generator which is consistent with our experimental results. Revenue neutrality holds, implying revenues to generators and average prices are similar in the uniform price and in a pure discriminative auction. We know of no similar results for soft cap markets.



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POWERWEB is the web-based experimental platform that is used for running experiments. Previous experiments using POWERWEB have already shown that relatively inexperienced players can identify and exploit market power in load pockets. When transmission constraints are not binding, auctions with six players and no uncertainty in the load have been shown to be efficient. We have also shown that when uncertainty is added to, for example, the load, the auction may no longer be efficient. There is evidence from operating electricity markets that prices can be driven above competitive levels when the largest supplier controls less than 20% of total installed capacity. This is accomplished by causing price spikes to occur. In experiments, uncertainty about the actual load and paying standby costs regardless of whether or not a unit is actually dispatched contribute to volatile price behavior. The objective of this paper is to describe a set of experiments designed to test the volatility of certain markets. The tests consider three different sets of rules for setting price when there are capacity shortfalls, and the following market structure:

1. Load is responsive to price

2. Price forecasts are made before market settlement

3 Units can be witheld

4. Suppliers are either:

   a) paid actual offers above a predetermined cap (a soft-cap auction) and a uniform price below that or

   b) A uniform price

## A National Experiment

Virtually all of today's electricity markets are single-sided, with limited demand-side patches like interruptable load or emergency demand response contracts available to a small set of customers. Current experimental work demonstrates the efficacy of modest, pre-specified price responsive load on offsetting capacity shortages and mitigating price spikes using experimental methods with human agents on both sides of the market

We are planning four experiments to be done in the month of October, 2001 to test our hypothesis with respect to soft cap and uniform price auctions response to load. The results of the experiments will be discussed during the presentation at the HICSS conference and presented later in another publication. Check the website http://www.pserc.cornell.edu for results or contact one of the authors. These experiments are (note: the sequence is important).

A. A Uniform price last accepted offer auction WITHOUT price responsive load (see the appendix for a complete description of the market)

B. A "soft cap" auction WITHOUT price responsive load

C. A soft cap auction WITH price responsive load

D. A Uniform price auction (LAO), WITH price responsive load

where "WITHOUT price responsive load" simply means a vertical stochastic demand (varying forecast with some error) and "WITH price responsive load" means adding fixed interruptible load contracts which are exercised at certain price points (i.e. a demand side played by software agents).

The experiments are to be run with a total of 40 subjects divided into 8 groups of 5 competitors each. Four of the 8 groups would do the four experiments in the order

A B C D

and the other four in the order ...

A B D C

Here the A-B sequence is justified by parallelism with the real world (i.e. California followed that progression) and the C-D and D-C segments allow us to compare C and D while accounting for ordering effects.

Each subject will play the part of a firm or company having 5 generators, each consisting of a single block with constant marginal cost. Offers would consist of price only, with the quantity of the offer equal to the entire capacity of the generator. The ISO can dispatch a generator anywhere between 0 and the entire capacity.

Each of the experiments A, B, C and D will be run for five rounds, where each round consists of three load periods (low, medium, high). So each subject will submit 15 numbers each day and get back 15 quantities, 15 prices, and 15 profits.

Underlying each experiment will be an AC model of an uncongested network with the 25 generators located at (at least) 6 locations.

Note that we could accelerate the experiment by running, say, A and B in parallel? However, this is not possible since A and B would no longer be independent. Learning from one contaminates the other. If C is performed and then D, C may contaminate D. But we also do D and then C so we will perform a second uncontaminated D for comparison to the first D. This is an issue of maintaining control in the experiment.

## The Basic Scenario for an Experiment

Before starting a new experiment, participants are required to complete a self-guided session playing against computer agents. This will increase the initial level of knowledge of the participants.

For all experiments, pilot tests are conducted using computer agents and students to determine that the characteristics of a scenario and the algorithms in PowerWeb are robust. This type of preliminary testing of the software is more important for industry professionals using the World Wide Web than it is for a typical experiment in a laboratory setting, because it is difficult to maintain interest among the participants if the software is unreliable.

With participants in an experiment located in different places, it may not be practical to conduct experiments in real time with all participants. Hence, one scenario under discussion is to collect inputs for the experiment each day at the convenience of the participants. Market outcomes will be computed over night and the results posted by the following morning. The obvious disadvantage of this situation is that it will take a long time to complete the number of rounds needed to reach an equilibrium in an experiment. (Even in simple experiments, we have found that 50 rounds or more are required when the market involves the standard features of a power grid.). Using experts instead of undergraduates will also help to speed the learning process, but it will still take a long time to reach consistency in behavior. Given this predicament, it is sensible to consider other ways to increase the speed of learning. An effective way to do this is to provide results for a range of different load patterns each day.

Assuming that there is a regular daily pattern of load (e.g. L, M, H, M, H, H, M, L, where L, M, and H are low, medium and high), a day-ahead market would solve the unit commitment and dispatching problem using a forecast of the load pattern. The actual pattern of load through the day would reflect unexpected deviations from the forecasted pattern (i.e. forecasting errors) and possibly the forced outage of one or more generators. The actual pattern of daily load is met by running a series of OPFs, subject to any constraints on operations from the day-ahead plan and incorporating new offers from a balancing market, if appropriate. Actual payments to generators (and by load centers) will be based on some specified combination of rules governing the day-ahead and the balancing markets. In other words, payments will be partially dependent on the realized pattern of daily load.

Simulating a wide range of realized patterns of daily load for one forecasted pattern would provide a lot of information for participants. For example, it would be possible to provide each generator with relative frequency diagrams of revenues received, costs incurred, and net profits. Hence, it would be possible to judge the robustness of a particular strategy for submitting offers. With experience, it may be possible to limit the number of realized daily patterns of load to reflect the likely range of daily outcomes. Even so, it will still be important to summarize the results in a compact way because the time that participants have for these experiments will be limited.

The real advantage of simulating results for different realized load patterns is that observed strategies for submitting offers that generate price spikes are inherently risky with only a small probability of getting a high profit (i.e. the probability of being dispatched is close to zero when a high offer is submitted, but this behavior may still be economically rational (see Mount (2000)). Hence, a lot more useful information will be available to participants if a simulated probability density function of profits for a particular set of offers is provided than one could get from the outcome of a single realization of load. Actual payments to participants would be based on the market solution in the day-ahead market and the average market solution for the balancing market.

A second way to enhance the information provided by a series of daily experiments is to get participants to submit offers for different daily load profiles. For example, specifying profiles for 1) a typical weekday, 2) a high-load weekday, and 3) a weekend day would provide a good approximation to the range of loads for a typical electric system. Using a weighted average of the market outcomes from the three load profiles (e.g. 50% , 30% and 20%) would give realistic estimates of the annual financial implications of operations for a participant. Some participants might decide not to submit offers for weekends, for example, and rely on making high profits when load is high. This type of behavior is difficult to produce in a standard experiment because participants are usually unwilling to "do nothing" for the duration of the experiment.

## The POWERWEB Platform: An Overview

Because of operational constraints on a power system, it is necessary to have a central agent acting as an independent system operator (ISO). In the previous implementations of POWERWEB, the ISO received offers to sell power from independently owned generation facilities. Based on a forecasted demand profile for the next day and the information gathered from the generator's offers, the ISO computed the optimal generator set points along with a corresponding price schedule which will allow the system to meet changing demand while satisfying all operational constraints.

As a web-based tool, POWERWEB may be used in several capacities. It can be utilized in a tightly controlled setting where a well-defined group of subjects are used for a very specific set of market experiments. It can also be used in a more open environment in which anyone on the web can log in and "play" as a generator competing against other generators, controlled by other humans or computer algorithms (agents), to generate power profitably. In either case, since POWERWEB is web-based it is accessible at all times to anyone with proper authorization, as long as the servers are up and running.

### A Typical Session

To eliminate the need to coordinate accesses (via phone, e-mail, etc.) and to prevent one user's actions from interfering with another's, all accesses occur in the context of a given "session". The session specifies which power system is being simulated, who "owns" which system resources (generators, etc.), and what market mechanism is in use. Multiple sessions can be active at any given time and activity in each is completely independent of the others. Typically, a user in a session will "own" one or more generating plants.

After logging in as a generator in a simple auction session, for instance, the user is taken to the *Offer Submission* page such as shown in Figure **1**, which displays the cost and capacity information for their generator. Here they can enter offers to sell power to the ISO.

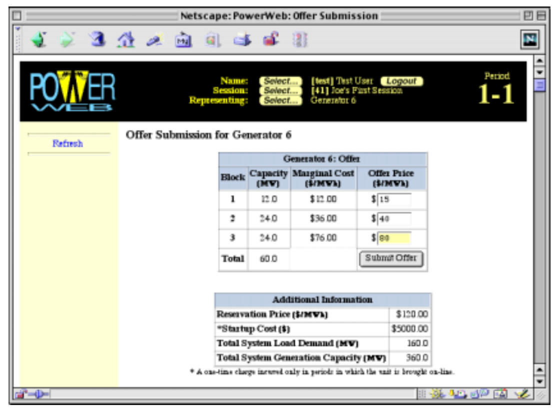


**Figure 1:** *Offer Submission* Page

When all participants have submitted their offers, POWERWEB's computational engine runs the auction according to the rules specified and reports back the results to the user. The *Auction Results* page is shown in Figure 2.

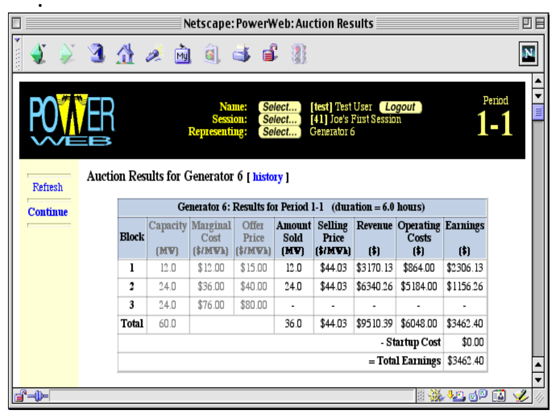


**Figure 2:** *Auction Results* Page

POWERWEB also has the capability to provide differing levels of information to the players, as specified by the experimenters. In a full information setting, each user would have access to the system information area, which gives tabular summaries of the system operation conditions as well as a "live" one-line diagram of the power system. Figure 3 shows the one-line diagram of a 6 generator, 30 bus system in POWERWEB's database. This diagram is generated dynamically by a Java applet from information retrieved from a relational database server. The diagram can be panned and zoomed and it is interactive in that clicking on an object such as a line, bus, generator, or load will query the database for information about the object. For example, selecting a bus will display the current information about real and reactive flows into and out of the bus as well as information about the current voltage level of the bus.

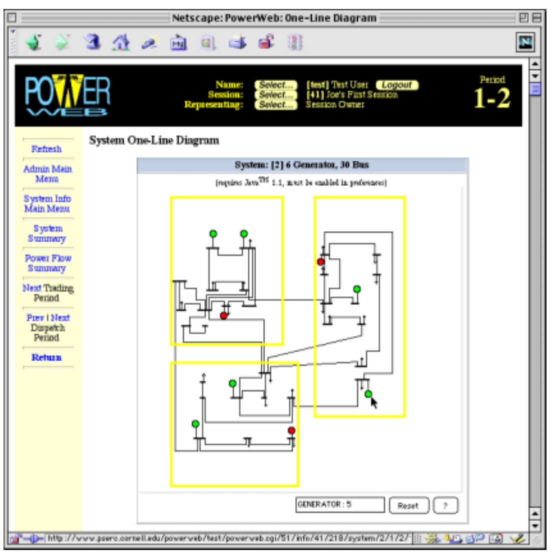


**Figure 3:** POWERWEB one-line diagram display, showing 30-bus system

The POWERWEB User's Manual, available from the POWERWEB home page at <http://www.pserc.cornell.edu/powerweb/> has more details regarding POWERWEB's functionality.

## The Underlying Optimal Power Flow

At the heart of the POWERWEB computational engine is an optimal power flow (OPF) program that is executed by the ISO in response to offers submitted in an auction. The market activity rules determine what offers are valid, but it is the ISO's role to ensure the safe and reliable operation of the network. By using an OPF, the ISO can legitimately allocate generation in an "optimal" way while respecting line flow constraints, voltage magnitude constraints, VAr constraints and any other constraints that are necessary to ensure safety and reliability. As a by-product, the OPF also produces the shadow prices associated with locationally based marginal pricing (LBMP) of power. These prices can be used as determined by the market mechanism being employed.

In the context of a market in POWERWEB, the OPF may be subjected to widely varying costs and therefore dispatches which are far from typical base case operation. It is important in such an environment that the OPF be extremely robust. The latest release version of the Matlab OPF solvers used in POWERWEB and more detailed documentation of the algorithms employed are available at no cost at <http://www.pserc.cornell.edu/matpower/> as part of the MATPOWER package.

PowerWeb has so far been used to examine the effectiveness of day-ahead electricity markets. Over 100 people have participated in electricity market experiments using this software platform. It has allowed for simple variation in the market mechanism being examined and also variation in the type of generators in the market. The two most important series of experiments conducted so far have examined the ability of generators to sustain prices above marginal cost in the presence of network constraints and the ability of generators to self-commit when faced with start-up costs.

## Acknowledgment

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# Appendix A

## Experiment 1: Uniform Price Auction with Stochastic Load (No Price Response)

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load and determines the market clearing price (last accepted offer) paid to all successful offers. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. When actual load is above 500 MW, some of your capacity is essential to meet load. However, the chances of load being above or below the forecast are the same.

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

**Your objective in the experiment is to maximize your profits over a series of 50 periods.**

**Summary**

*Auction*: Uniform – Last accepted offer

*Periods*: 50

*Load:* Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW

*Price Response*: Load is price inelastic

*Standby Charges*: $5/MW for each block

*Shortfall Mechanism*: Random recall with price set to the highest offer

*Recall Charge*: $10/MW for each block

*Fixed Interest Charge*: $1200/period

*Exchange Rate*: 1/6000

**Experiment 2: Soft Cap Auction with Stochastic Load (No Price Response)**

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load. The auction is divided into two parts. A clearing price for all **offers below $75/MWh** is determined in a **uniform price auction** (last accepted offer ≤ $75/MWh). If **offers above $75/MWh** are needed to meet load, the purchased blocks are paid the actual offers > $75/MWh in a **discriminative auction**. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. Load is not responsive to price.

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

**Your objective in the experiment is to maximize your profits over a series of 50 periods.**

**Summary**

*Auction*: Uniform ≤ $75/MW, Discriminative > $75/ MW

*Periods*: 50

*Load:* Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW

*Price Response*: Load is price inelastic

*Standby Charges*: $5/MW for each block

*Shortfall Mechanism*: Random recall with price set to the highest offer

*Recall Charge*: $10/MW for each block

*Fixed Interest Charge*: $1200/period

*Exchange Rate*: 1/6000

**Experiment 3: Soft Cap Auction with Stochastic Load (Price Responsive)**

This experiment has not yet been written

**Experiment 4: Uniform Price Auction with Stochastic Load (with Price Response)**

You are one of six suppliers in an electricity market. Each supplier owns 100 MW of capacity, divided into five blocks. Offers to sell these blocks can be submitted into an auction. An ISO selects the least expensive combination of offers to meet the system load and determines the market clearing price (last accepted offer) paid to all successful offers. For each period, you will be given a forecast of the system load. The actual load is uncertain but it falls into the range of **Forecast ± 20 MW**. The change from Experiment 1 is that **Contracts for Interruptible Load** exist that are automatically exercised at specified prices. The details of these contracts are not public information.

The operating costs of your capacity have two components. The first is the operating cost/MWh for a capacity that is dispatched. The second is a fixed standby charge of **$5/MW** for submitting an offer. Hence, standby costs are paid when a block is offered into the market even if it is not dispatched. Withholding blocks from the auction is the only way to avoid standby charges for those blocks (the "submit offers" screen for POWERWEB has buttons for withholding blocks). If the total capacity offered into the auction is less than the actual load, the ISO recalls enough additional capacity to meet load. Recalled capacity is selected at random from the blocks that were withheld from the auction. A recall charge of **$10/MW** must be paid if a block is recalled, as well as the operating cost for the capacity purchased.

**Your objective in the experiment is to maximize your profits over a series of 50 periods.**

**Summary**

*Auction*: Uniform – Last accepted offer

*Periods*: 50

*Load:* Forecast = 490MW ± 60MW, Actual = Forecast ± 20 MW

*Price Response*: Contracts for interruptible load

*Standby Charges*: $5/MW for each block

*Shortfall Mechanism*: Random recall with price set to the highest offer

*Recall Charge*: $10/MW for each block

*Fixed Interest Charge*: $1200/period

*Exchange Rate*: 1/6000